The Right Way to Calculate Fuel Cost Conversions

FROM the FIELD

By Paul Norton

The federal excise tax in the United States is 24.4 cents per gallon for diesel fuel and 48.45 cents per thousand standard cubic feet for compressed natural gas. Here's an easy question: Which tax is higher and by how much?

A certain line-haul truck travels 6.2 miles on a gallon of diesel fuel and a comparable truck travels 3.2 miles on a gallon of liquefied natural gas. Another apparently easy question: Which truck is more fuel efficient?

The answers to these questions may be less obvious than you think. Hence the need for standard units of measure to compare natural gas and conventional fuels. It is common to see fuel cost, fuel efficiency and fuel tank capacity expressed in "gasoline equivalent gallons" or "gallons gasoline equivalent." This article outlines how these units are derived and used.

The basis of comparison for these derived units is the fuel's energy content. Energy content goes by several names: calorific value, heat of combustion, thermal value, heat content and heating value. The term "heating value" is used most often when discussing motor fuels. This quantity can be expressed in two ways: the higher (or gross) heating value and the lower (or net) heating value. Both measure the energy released during combustion per unit mass of fuel.

Water vapor is formed during the combustion process. If this water vapor is captured and condensed, energy is released during condensation. The energy released from the condensation of this water vapor is the difference between the higher and lower heating values.

The higher heating value of a fuel is measured in a device called a bomb calorimeter. In a bomb calorimeter, a known quantity of fuel is burned and the water vapor is condensed. The energy released is measured and divided by the mass of the fuel burned to yield the higher heating value. To calculate the lower heating value, the latent heat of the water vapor is subtracted from the higher heating value. In an internal combustion engine, the water vapor formed during combustion is exhausted. For this reason, it is more common to use the lower heating value when comparing motor fuels.

The lower heating value is often expressed in terms of fuel volume rather than fuel mass because liquid fuel is commonly measured in gallons. The representative lower heating values of various fuels are shown in Table 1.

The lower heating value of compressed natural gas (CNG) is presented in British Thermal Units (Btu) per pound and Btu per standard cubic foot (Scf). All the heating values presented in the table should be understood as representative, not absolute, because these fuels are mixtures of various hydrocarbons and the heating value of a specific batch of fuel depends on its exact composition.

Table 1: Representative Heating Values of Various Fuels

Fuel	Lower Heating Value	Source	Comment
Unleaded Gasoline	115,400 Btu*/gal	Davis, Strang, "Transportation Energy Data Book: Edition 13," ORNL-6743, 1993	
Diesel	#2 diesel fuel: 128,980 Btu/gal #1 diesel fuel**: 125,780 Btu/gal	Dickson, Woodward, "Diesel Fuel Oils, 1991," NIPER-172PPS, October 1991, and "Thermal Properties of Petroleum Products", Government Printing Office, November 1992.	
Compressed Natural Gas	20,356 Btu/lb 926.2 Btu/scf***	Liss, "Fuel Issues For Gas Engines and NGVs," Proceedings, 1993 Windsor Workshop on Alternative Fuels, . June 14-16, SAE 930696, 1993	Average for the United States from the Gas Research Institute
Liquefied Natural Gas	78,000 Btu/gal	Perry's Chemical Engineering Handbook, 5th Ed., 1973, p. 9-13	Higher heating value from reference = 86,000 Btu/gal**** At -263 °F and density of 3.46 lb/gal. Lower heating value was calculated from this higher heating value

*Btu = British Thermal Unit

** #1 Diesel fuel is used during cold weather in some locations to prevent fuel thickening and gelling.

*** scf = standard cubic foot

**** The higher heating value is often presented by suppliers of liquefied natural gas.

Complicating Factors

• Gas Composition

The composition of CNG or liquefied natural gas (LNG) at different locations can vary significantly, and the lower heating value of the gas is affected by its composition. For example, LNG from peak-shaving plants is typically composed of about 95 percent methane, four percent ethane, and one percent propane and heavier hydrocarbons. The lower heating value of this liquefied gas saturated at atmospheric pressure is about three percent higher than pure methane. Natural

gas delivered to homes and businesses in Golden, Colo., where the National Renewable Energy Laboratory is located, is typically composed of about 84 percent methane, six percent ethane, one percent propane and other hydrocarbons, six percent nitrogen, two percent carbon dioxide and one percent oxygen. The lower heating value of this gas is about 890 Btu per Scf, which is about four percent lower than the national average.

• **Saturation Pressure**

As the saturation pressure of LNG increases, its saturation temperature increases and fuel density decreases. Some natural gas engines require pressures as high as 150 pounds per square inch (psi) above atmospheric pressure to operate.

Most fuel systems condition the LNG in the fuel tank to at least the pressure required by the engine. Therefore, the heating value of the LNG in the tank will be different from the heating value at atmospheric pressure due to the decrease in density. For example, the heating value of saturated liquid methane at 150 psi above atmospheric pressure is about 16 percent less than the heating value at atmospheric pressure.

Calculating Equivalent Gallons

An "equivalent gallon" is simply the quantity of natural gas fuel that has the same energy content as a gallon of the reference fuel

For example, a gallon gasoline equivalent (gge) of CNG is the quantity of CNG that has the same energy content as a gallon of gasoline. A gallon of unleaded gasoline contains 115,400 Btu. About 125 Scf of national average CNG would also contain 115,400 Btu. Therefore, about 125 Scf of the national average CNG equals one gge.

Other conversion factors are shown in Table 2. These conversion factors are based on the lower heating values given in Table 1.

Now we can use these conversion factors to answer the questions posed at the beginning of this article.

The following equation can be used to answer the first question about excise tax:

$$\frac{48.4 \text{ cents}}{1000 \text{ scf CNG}} \times \frac{139 \text{ scf CNG}}{1 \text{ gal No. 2 diesel}} =$$

$$\frac{6.73}{\text{gal No. 2 diesel}} = \text{6.73 cents per diesel equivilent gallon}$$

Table 2: Conversion Factors for Energy Equivalent Gallons

Conventional Fuel	CNG	CNG	LNG
1 gall. of unleaded gasoline =	5.67 lb. of CNG =	125 scf of CNG=	1.48 gall. of LNG
1 gall. of #2 Diesel fuel =	6.34 lb. of CNG =	139 scf of CNG =	1.65 gall. of LNG
1 gall. of #1 Diesel fuel =	6.18 lb. of CNG =	136 scf of CNG=	1.61 gall. of LNG

At less than one-third the tax on diesel, the tax on CNG is a bargain!

To calculate fuel efficiency and answer the second question, use the following formula:

$$\frac{3.2 \text{ miles}}{1 \text{ gal LNG}} \times \frac{1.65 \text{ gal LNG}}{1 \text{ gal No. 2 diesel}} =$$

$$\frac{5.3 \text{ miles}}{\text{gal No. 2 diesel}} = \text{5.3 miles per diesel equivilent gallon}$$

This is about 15 percent less efficient than the diesel truck that achieved 6.2 miles per gallon.

Know Thy Assumptions!

The energy equivalent gallon is a powerful tool for comparing fuels, but like any other tool, it must be used with care. If you use the conversion factors presented here, keep in mind the conditions under which they are valid. To make a fair comparison, the conversion factors may need to be corrected for the specific natural gas fuel composition and pressure as well as for the specific conventional fuel used in your application. For more information, call the National Alternative Fuels Hotline at 800-423-1DOE or visit the National Renewable Energy Lab's Alternative Fuels Data Center internet site at *http://www.afdc.doe.gov.*

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